LARGE SCALE ELECTROMAGNETIC MODELING OF ACCELERATOR STRUCTURES & COMPONENTS USING HIGH PERFORMANCE COMPUTERS*

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Electromagnetic Code Development at SLAC

- Originated in NLC accelerator structure R&D - 2D finite element eigensolver ***YAP***, ***Omega2***, for Detuned Structure (DS) design

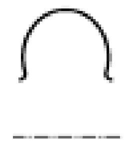
- Continued with 2D parallel ***Omega2P*** to analyze dipole wakefields in DS and 3D ***Omega3*** for Damped, Detuned Structure (DDS) design

- Developed parallel ***Omega3P*** and parallel time-domain solver ***Tau3P*** under ***DOE Grand Challenge*** to perform *LARGE SCALE* simulations

- Propose support from ***DOE Scientific Simulation Initiative (SSI)*** to dramatically increase present effort towards developing advanced modeling tools to design next-generation accelerators

Application To Linear Collider Structure Design

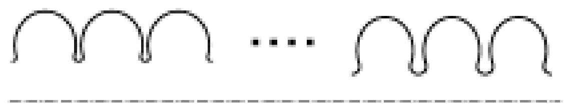
- Optimized Detuned Cell



RF parameters

Omega2

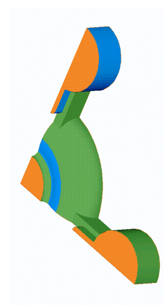
- Detuned Structure
(206 cells)



Transverse
Wakefields

Omega2P

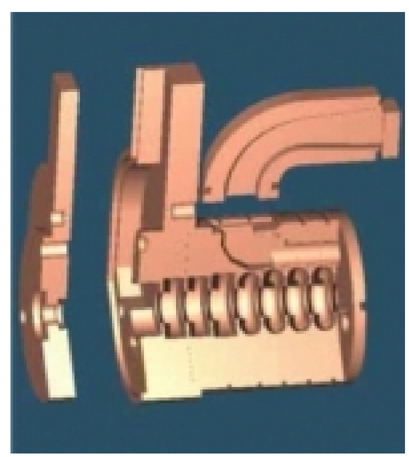
- Damped Detuned Cell



RF parameters

Omega3

- DDS Structure
(206 cells)

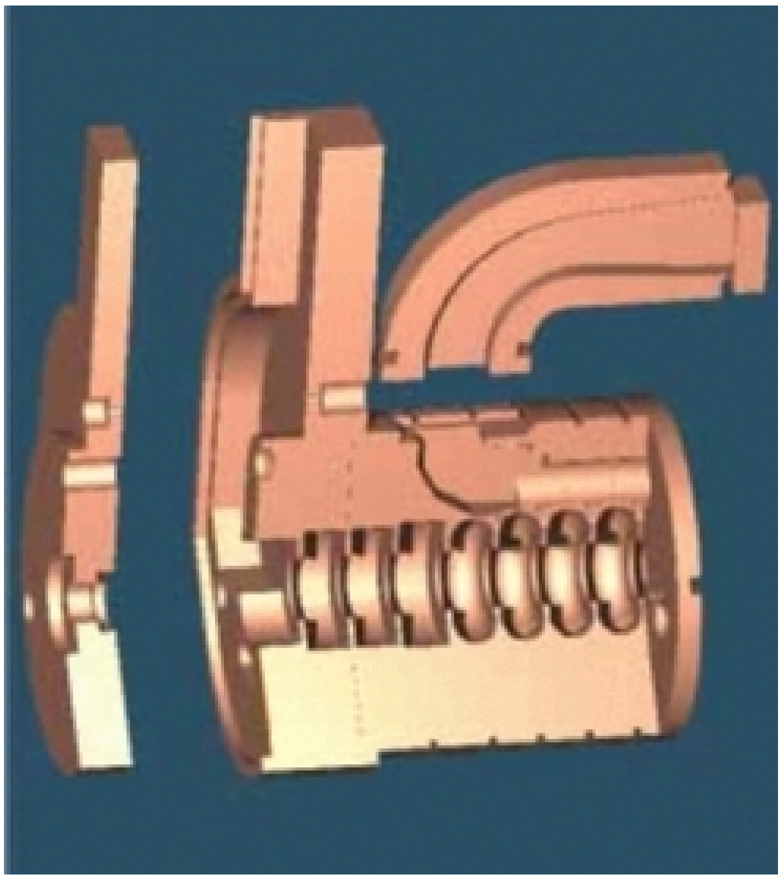


Transverse
Wakefields

Omega3P

Large Scale Electromagnetic Simulations

DDS for the NLC



- Cell Design requires frequency error of 1 part in 10,000 with mesh size close to fabrication tolerance (no tuning of cell)

- Wakefield Analysis needs entire section (206 cells) modeling to verify the DDS scheme in suppressing emittance growth

Simulating these problems spans a range from 10^6 to 10^9 degrees of freedom !

"High-Resolution" design and "System-Scale" analysis are only possible on <u>Massively Parallel</u> Computers

Parallel Electromagnetic Field Solvers

Parallel Processing is necessary to enable ***LARGE SCALE*** simulations

Omega3P - *3D Parallel Eigensolver for calculating resonant modes of cavities*

Tau3P - *3D Parallel Time-Domain Solver to simulate transmission structures*

Solver features:

- C++ implementation
- Message Passing Interface (MPI) for communication (e.g. SGI/CRAY-T3E)
- Reuse existing parallel libraries (e.g. ParMETIS, AZTEC)
- Unstructured grid for conformal meshes (e.g. FE formulation)
- New solver algorithms for fast convergence & scalability
- Adaptive refinement to improve accuracy & optimize computing resources

Towards High Performance Computing !

High Performance Computing in Electromagnetics

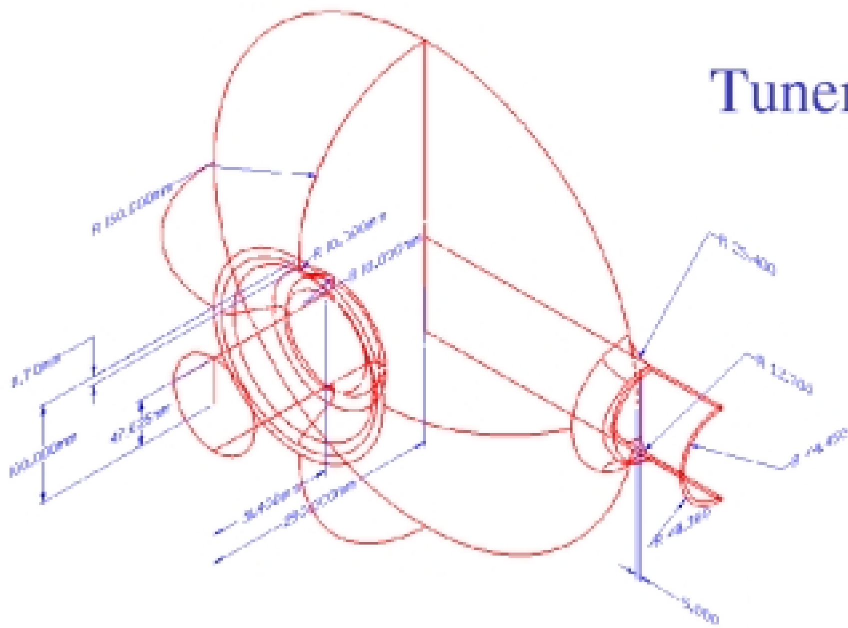
SLAC experience:

- Parametric Geometry - CAD models to facilitate optimization
- Mesh Generation - impacts matrix conditioning/time-stepping
- Domain Decomposition - partitioning tools for load balancing
- Parallel Solvers - scalable algorithms with fast convergence
- Adaptive Refinement - improve accuracy/optimize resources
- Visualization - efficient post-processing of large data sets
- Performance/Error Analysis - computer science/applied math

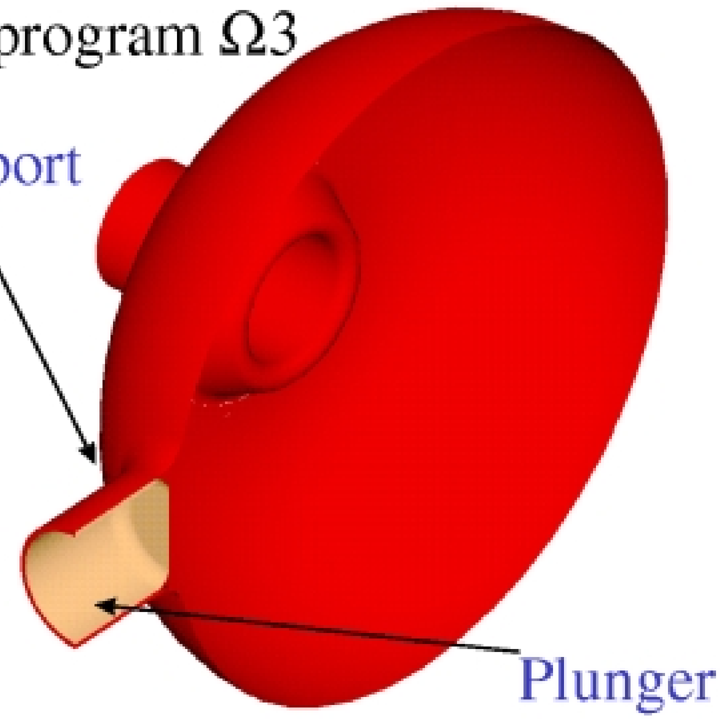
Since HPC is a limited, shared resource (e.g. T3E at NERSC) , LARGE SCALE simulation productivity depends on successfully integrating the combined efforts of a multi-disciplinary team of physicists, applied mathematicians, computer scientists, software engineers, geometry builders …. Bottleneck is always caused by the weakest link!

Parameterized solid model

– Analyze cavity with tuner using program Ω3



Engineering drawing



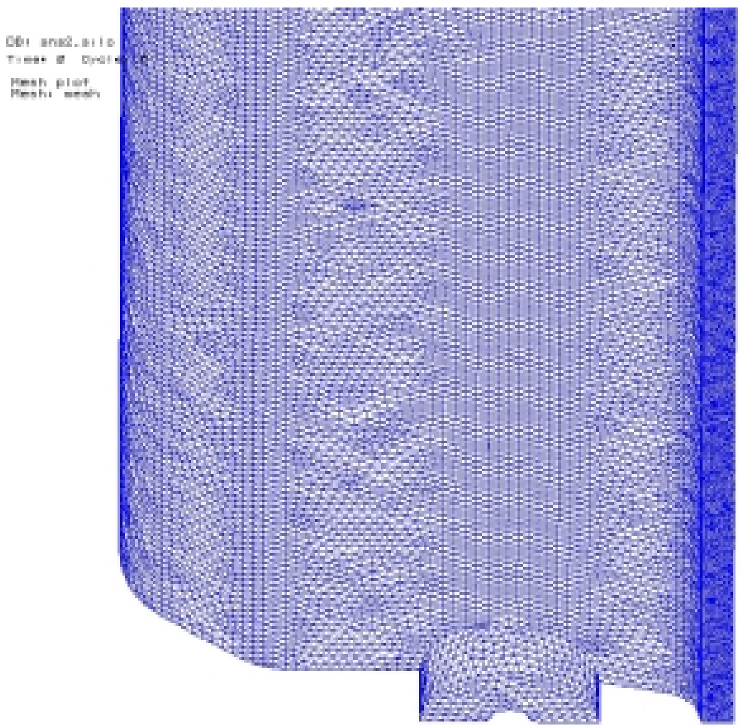
Parametric Solid model

- Interface to a variational solid modeler EMS/Intergraph
- Can resolve necessary features (e.g., small distance between the tuner port and the plunger)
- Easy to change plunger position

Mesh Generation

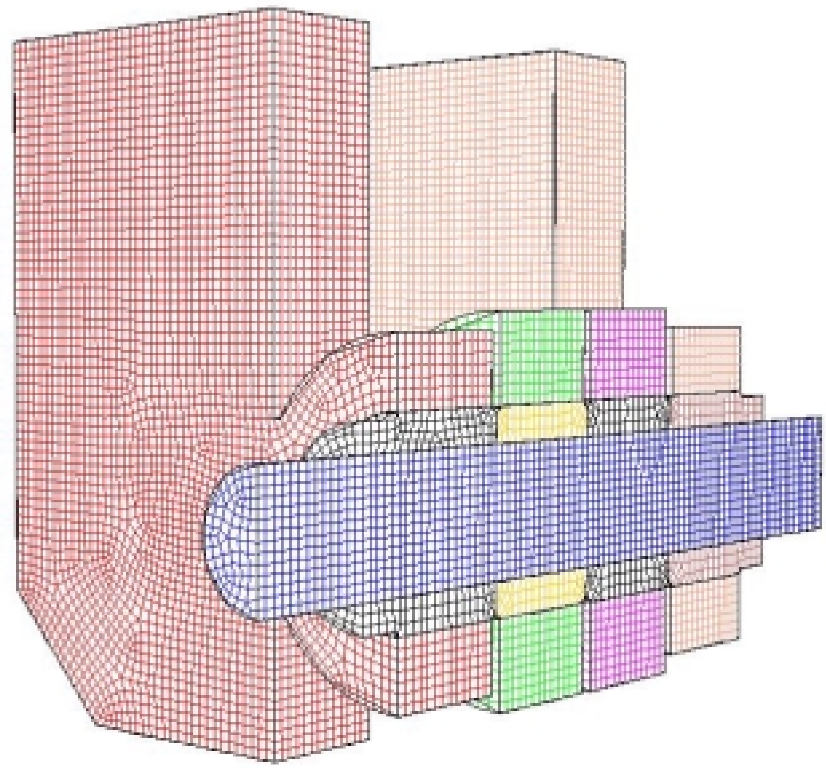
Size of meshes limited by workstation memory - <u>Parallel Mesh Generation</u>

Tetrahedral mesh for ***Omega3P*** from ***SIMAIL*** (Simulog)



RFQ Cavity for SNS

Hexahedral mesh for ***Tau3P*** from ***CUBIT*** (Sandia)

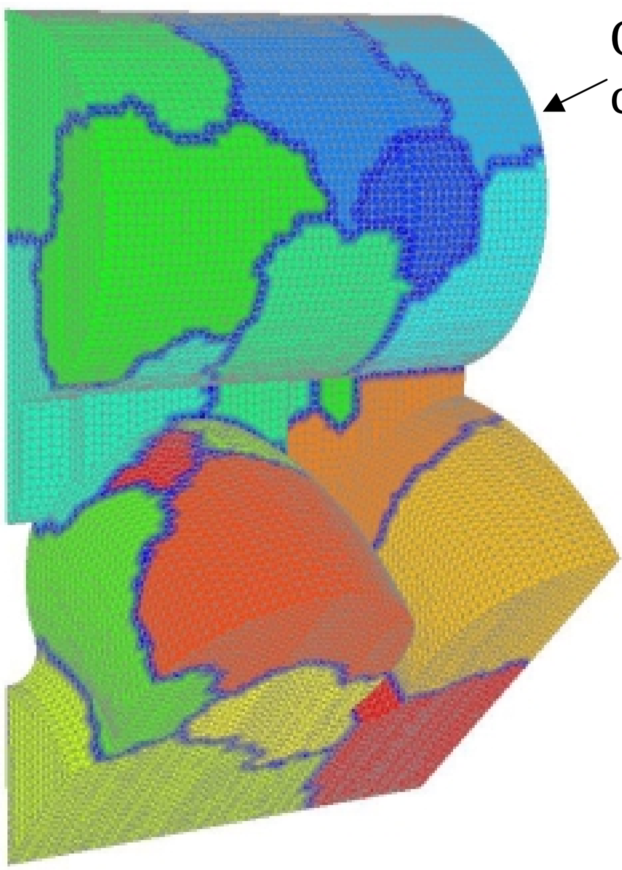


Input Coupler for NLC

Domain Decomposition

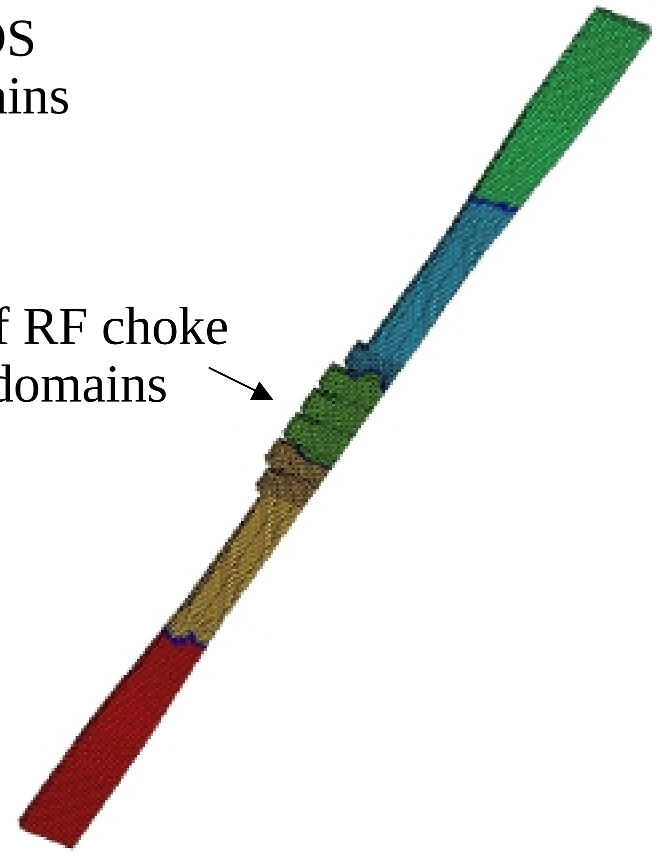
Partitioning to optimize load balance & minimize communication

Omega3P



Octant of 1.5 DDS cell into 16 domains

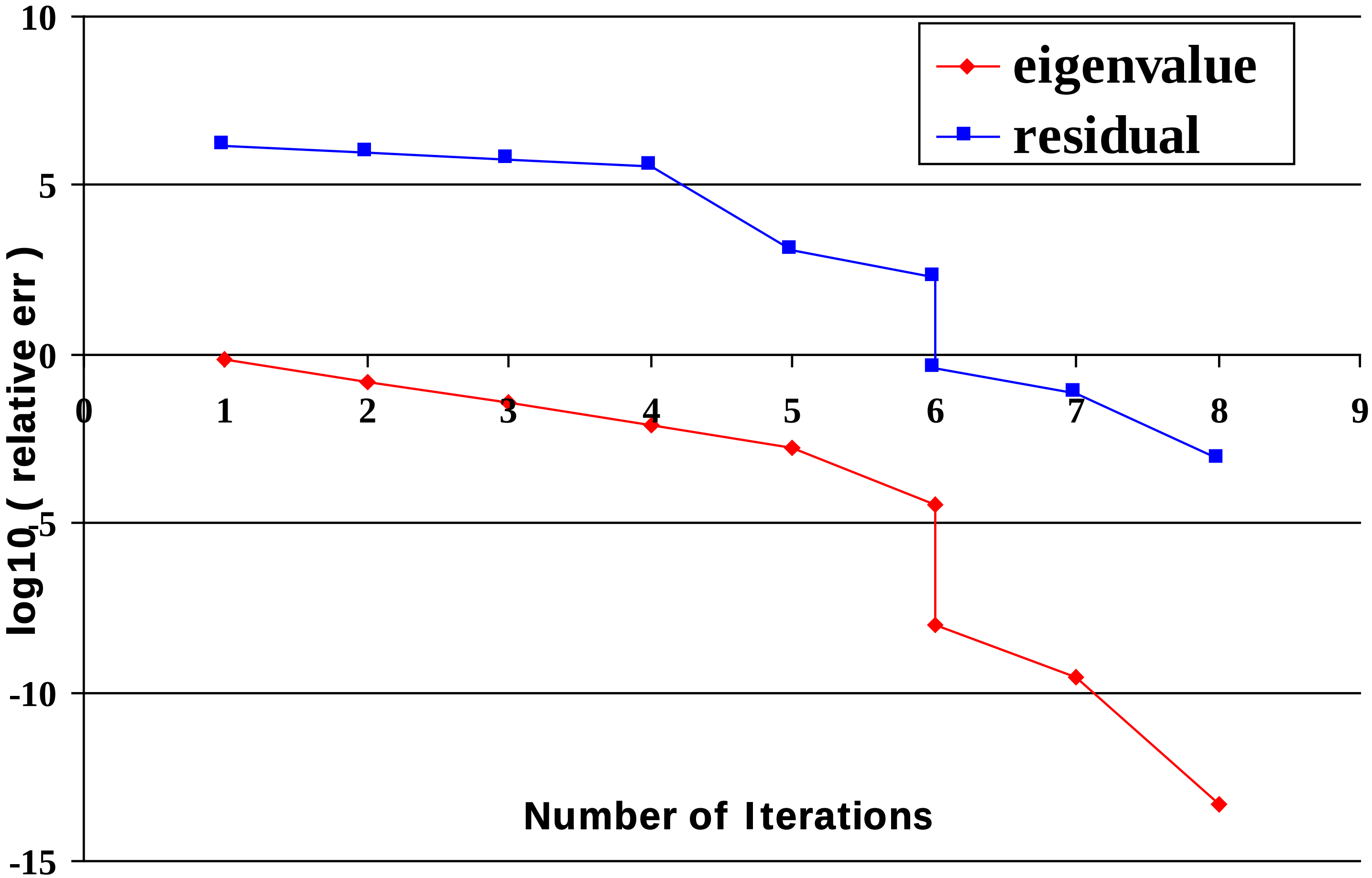
Tau3P



Quarter of RF choke into 4 domains

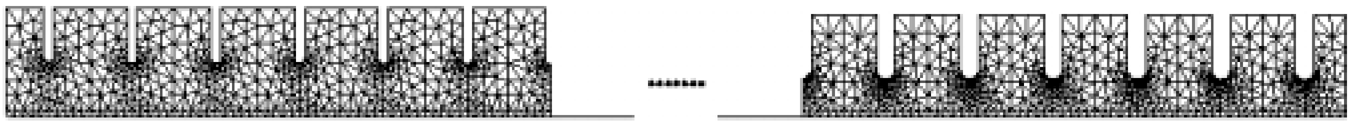
Parallel Solver

Omega3P *convergence on DDS example with 500K DOF's*

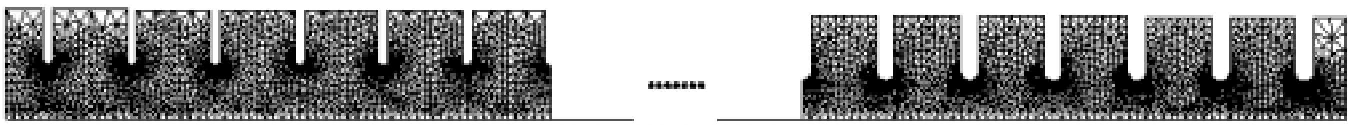


Simulation Results for NLC Detuned Structure

- initial mesh:



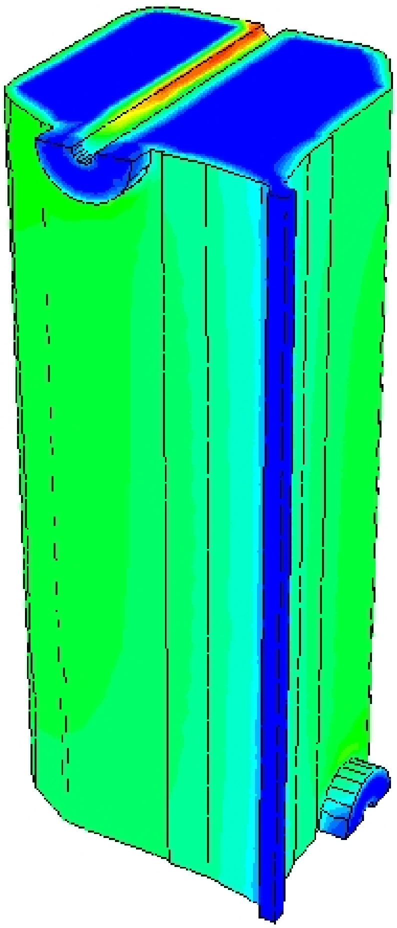
- adaptive refinement:



Mesh level	DOF	Solution time	Memory
0	227,769	25 minutes	4.0 GB
1	651,194	98 minutes	6.2 GB

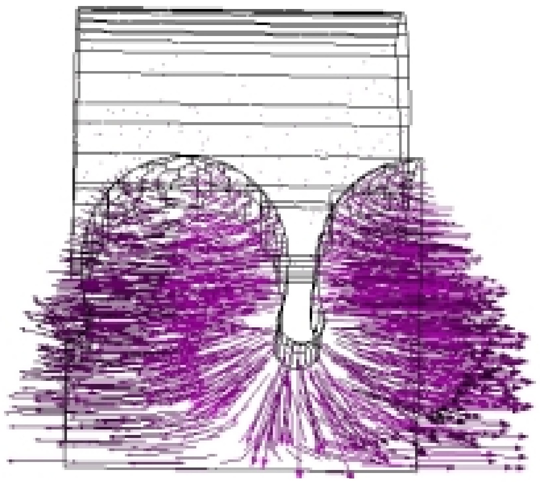
Visualization

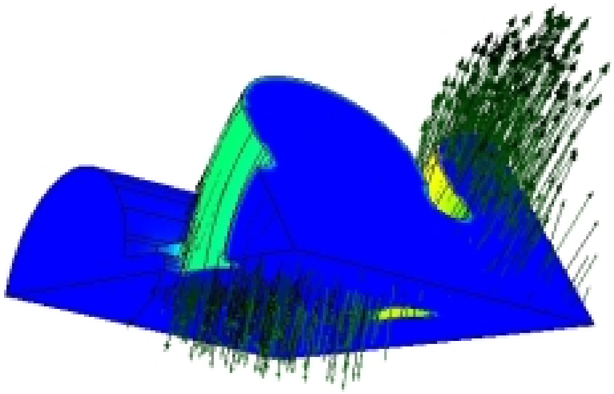
Parallel Rendering will be needed with LARGE data sets



MODULEF
(INRIA)

MESHTV
(LLNL)

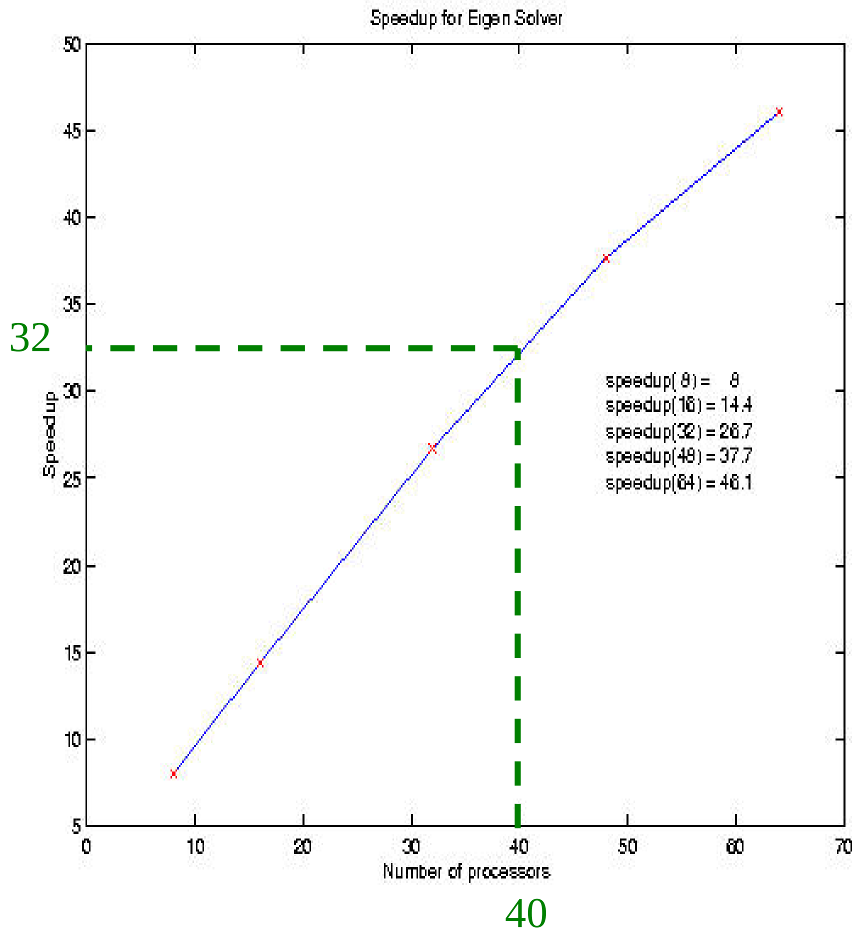




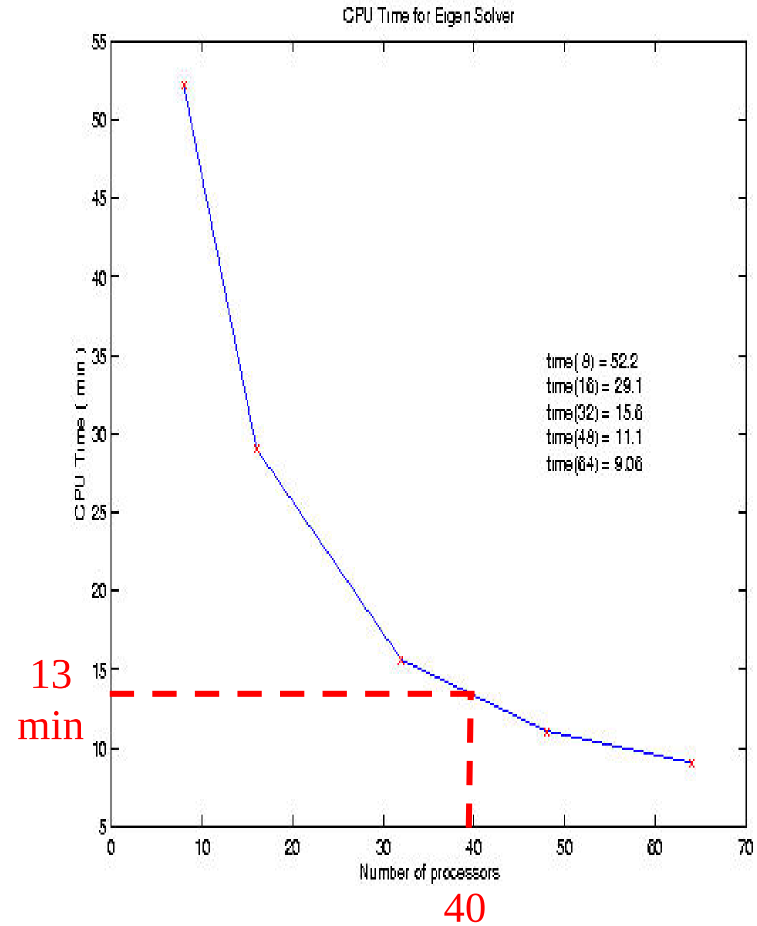
Parallel Performance

Omega3P *performance on DDS example with 500K DOF's*

Speedup



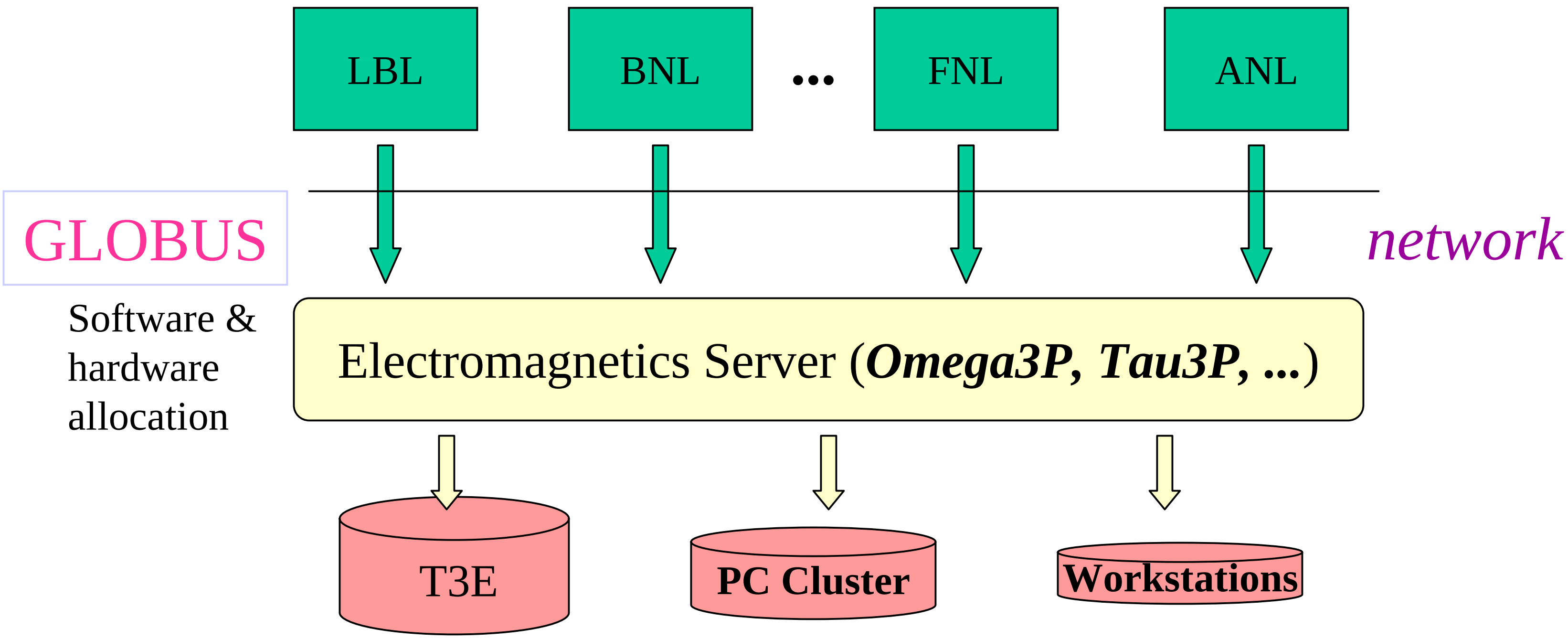
CPU Time



Capability Sharing

Support DOE Labs in designing next-generation accelerators
*(**NLC, SNS, LCLS, Muon Collider, Light Sources …… **)*

"Client/Server Model with GUI front end" - NERSC, ANL & STAR Inc.



34-node PC Cluster

Omega3P running on cluster using MPI

Performance is within 25% of T3E up to 16 processors

Possible low cost, scalable alternative to supercomputers

Effective resource for high resolution component design

- Collaborative effort - SLAC (ARDA, SCS, BaBar) & LBL (NERSC)
- Specs: 17 Dell 410 systems, each with dual 450 MHz Pentium II processors, 256 MB memory, one 9 GB disk connected with a Cisco 5505 Fast Ethernet switch
- Operating system: RedHat Linux version 2.0.36

Planned Areas of Work/Collaboration

Omega3P: Complex eigenvalues - in progress

Tau3P: Wakefields - in progress

Phi3P: Static solvers - starting

Particles: Tracking - surface physices (C. Birdsall/UCB)

Parallel mesh generation - *Sandia & UCB*

Domain decomposition - *NERSC & NASA Ames*

Parallel preconditioners - *NERSC & UCB*

Adaptive refinement - *UT Austin*

Parallel rendering - *UC Davis*

Performance analysis - *NERSC*

Electromagnetics server - *NERSC, ANL & STAR Inc.*

Related Papers in this Conference

Thursday Poster Session CONCOM D06:

THA67 OMEGA3P: A Parallel Eigensolver for the DOE Grand Challenge

THA68 TAU3P: A Parallel Time-Domain for the DOE Grand Challenge

THA72 3-D Optimization Using a Client/Server Software Topology

Friday Poster Session LINCOL A03:

FRA19 A Compact RF Power Coupler for the NLC Linac

FRA41 RDDS Cell Design and Optimization for the NLC Linac